DISCOVERY OF DIRECTIONAL COMMUNICATION CHANNELS IN AD HOC NETWORKS

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ABSTRACT

We examine the process of discovering directional antenna communication channels in ad hoc networks and discuss how available location information can be used to guide the search. We outline methods to estimate the bearings of potential directional links and focus the search in sectors where greater payoff is expected, thus increasing its effectiveness and reducing unnecessary probing.

1 INTRODUCTION

Directional antennas (DA) have a non-uniform gain distribution with its maximum focused in a constricted region of space, often referred to as the DA *beam*. In comparison with their omnidirectional counterparts (ODAs) at equivalent energy output, DAs provide a SNR that is higher within the beam and lower outside it. This translates into greater communication reliability and range within the beam; while the lowered gain outside it allows for increased spatial reuse [Ramanathan, R., 2001] and LPI/LPD. Directionality has its drawbacks too. Whereas, an ODA can detect/receive a signal originating from any possible direction and a single transmission is sufficient to reach all neighbors, a DA must be pointed at the signal source for reception and multiple transmissions must be performed to cover all neighbors. To exploit the advantages of both communication modes, we assume that nodes are equipped with an ODA in addition to any DAs.

There are two possible cases when considering DA communication between a pair of nodes: (1) one node uses a DA while the other uses an ODA; or (2) both nodes use DAs. Obviously, the latter provides the greatest range by combining the gains of directional transmission and directional reception. In either case however, the corresponding DA beams must be oriented correctly. This is non-trivial in ad hoc settings, since nodes must determine each other's bearings before DA communication can occur. The straight-forward approach to achieving this is blind probing, where the DA periodically sweeps through every possible direction, in sequential or random order, and transmits a probe packet that includes the sender's location. Nodes that receive this packet simultaneously identify a potential DA link with the sender and determine its bearing based on the location. This approach is simple and thorough, but it does require frequent transmissions, persistently drawing energy, interfering with on-going communication, and potentially compromising LPD. Blind probing could be eliminated, if nodes advertise their locations via established ODA and DA links. This would enable them to gauge whether a directional link is possible given the distance between them, and thus to transmit probes only in the directions where potential recipients are identified. However, this approach will fail to establish DA links for nodes that do not already have a communication path between them, since they will be unable to exchange location information. Thus a combined approach is called for, in which blind probing is utilized in a limited fashion, guided by advertised or deduced node position information.

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2 GUIDED DIRECTIONAL PROBING

Guided directional probing is outlined as follows: (1) advertise any known location information about each 1-hop neighbor (ODA or DA) to all 1-hop neighbors[1]; (2) identify any 2-hop neighbors with which a DA link may be established, determine their probable bearing or range thereof, and probe these sectors to establish or discount the potential links; (3) identify any sectors where a network partitioning is suspected (e.g., where no 2- or 1-hop neighbors reside) and probe them periodically.

2.1 Determining Neighbor Bearings

We consider three cases depending on the common reference system available in the network: (1) GPS/LPS; (2) a common reference bearing (CRB) external to the network, e.g. geographical or magnetic North; (3) inter-network reference bearings, e.g. a common neighbor, a base station, etc. In Case 1, nodes have sufficient information to determine each other's distance and bearing; here blind probing can be strictly limited to sectors where no neighbors reside, indicating a potential network partitioning in that area.

[1] This supplies every node with information on all nodes and links within a distance of 2 hops.

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If GPS/LPS is unavailable (Cases 2 and 3), inter-node distance can be estimated based on signal propagation measurements such as signal attenuation (difference between transmitted and received signal strength), time of arrival (TOA), etc. [Patwari, N. et al., 2001]. Direction can be estimated based on the DA azimuth and elevation, at which a directional link was established. By advertising this information neighbors can triangulate their locations in relation to one another. For example, if nodes *A* and *B* know each others bearings, b_i, and distances, d_i, and *A* advertises the existence of *B* and *C* as $\{B(b_1, d_1), C(b_2, d_2)\}$, then *B* can deduce the location of *C* through trigonometric calculation. Furthermore, any other nodes for which only distance estimates can be obtained based on ODA connections to *A* and/or *B* can be localized to one or two possible sectors (Fig. 1). Although not a necessity, a CRB can greatly facilitate this process, e.g. in a 2-D case, if *A* receives a probe from *B* stamped as transmitted at bearing *b* in relation to the CRB, then *A* can infer that *B* is at bearing 180^o-*b*, eliminating the need of *A* to search for *B*. A CRB can either be pre-determined (e.g. North, if nodes feature a compass) or established on-the-fly among a group of nodes (e.g., the bearing of a common neighbor) [Capkun et al., 2001]. The latter can be achieved as long as nodes form fully connected groups of at least three members. Then triangulation can be performed to identify the relative locations of nodes and limited blind searches are needed to determine the bearing of one of these nodes to serve as a CRB for the group. As opposed to Case 1, Cases 2 and 3 will require more extensive probing because the bearings of potential neighbors are not exact but rather one or two fuzzy sectors, possibly requiring several probes to be transmitted to ensure they are fully scanned.

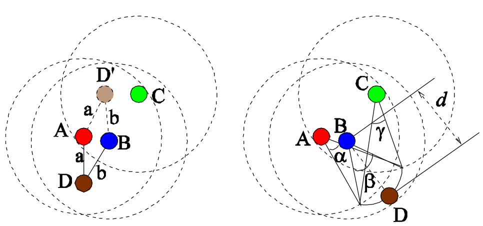

Figure 1. **Left:** *D* is within OL range of *A* and *B*, but not *C*, thus *D*' is eliminated as a possibility. **Right:** *D* is within OL range of *B* at distance *d*, thus the search angles α, β and γ are deduced.

2.2 Directional Probing Coordination

A node can be in one of the two directional probing (DP) modes: Search (DPS) or Maintenance (DPM). DPS is invoked when potential directional links (DLs) are identified through the localization techniques described above. Initially, nodes establish ODA links (OLs) and exchange connectivity/location information. Within each 1-hop neighborhood the highest degree node initiates DPS. Potential neighbors whose bearings have been determined are probed first; if any neighbors remain to be found the unprobed sectors are scanned sequentially. Upon exchange and processing of the neighbor information obtained from each DPS round, additional searches may be invoked to scan sectors where new potential neighbors are identified. This process iterates until all nodes have established or discounted the potential DLs identified. When complete, nodes switch to DPM, where directional probes are only transmitted in the on established DLs. Following this, DPS is invoked either when new potential neighbors are detected, or periodically to scan sectors where no neighbors reside, indicating possible partitioning of the network.

3 PERFORMANCE

As an initial performance gauging, we estimate the width of the sectors probed blindly by each node, summed over all nodes. For tractability, we base the estimate on a 2-D grid node laydown. We express this measure as a fraction of the total sector space in the network as:

$$S(d) = \frac{d^2}{1+(2d-1)r+(2d^2-4d+1)r^2},$$

for a grid composed of *d*x*d* nodes, with a maximum DA transmission range, *r*, specified in units of inter-node distance. It can be observed that *S(d)* quickly drops to below 0.2 in clusters as small as 16 nodes with *r*=2, indicating a 5-fold reduction of the sector space covered by blind probing. The grid laydown obviously makes this an optimistic estimate but nevertheless it indicates significant potential for restricting blind probing.

4 CONCLUSION

We outline methods to enhance the effectiveness of directional link probes and reduce their frequency in ad hoc networks by utilizing available node location information. Approximation shows that unnecessary blind probing can be significantly restricted.

REFERENCES

Capkun, S. et al., 2001: GPS-Free Positioning in Mobile Ad-Hoc Networks, *Proc. 34th Annual Hawaii Int. Conf. on System Sciences*, Maui, HI, Vol. 9, 9008-9023

Patwari, N. et al., 2001: Relative location in wireless networks, *IEEE Vehicular Technology Conference*, Rhodes, Greece

Ramanathan, R., 2001: On the performance of ad hoc networks using beamforming antennas, *Proc. ACM MobiHoc 2001*, Long Beach, CA, 95-105

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